# Advanced Methods for Passive Acoustic Detection, Classification, and Localization of Marine Mammals

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## LONG-TERM GOALS

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For effective long-term passive acoustic monitoring of today's large data sets, automated algorithms must provide the ability to detect and classify marine mammal vocalizations and ultimately, in some cases, provide data for estimating the population density of the species present. In recent years, researchers have developed a number of algorithms for detecting calls and classifying them to species or species group (such as beaked whales). Algorithms must be robust in real ocean environments where non-Gaussian and non-stationary noise sources, especially vocalizations from similar species, pose significant challenges. In this project, we are developing improved methods for detection, classification, and localization of many types of marine mammal sounds.

## OBJECTIVES

We are developing advanced real-time passive acoustic marine mammal detection, classification, and localization methods using a two-pronged approach: developing improved DCL algorithms, and developing standardized interfaces and software.

First, we are developing, testing, and characterizing advanced DCL algorithms:

1. Echolocation click classification. Algorithms are being developed and tested for several species of beaked whales and small odontocetes.
2. Tonal signal detection and classification. Algorithms are being tested for several species of mysticetes and for small odontocetes.
3. Multi-sensor localization. Algorithms will be developed and tested on datasets containing sounds of both odontocetes and mysticetes.

Second, improved DCL software will be developed and both existing and new methods will be made available to users. The key contribution will be the development of four well-specified interfaces, for detection, feature extraction, classification, and localization. We will implement the "front end" of these interfaces in widely-used and critical software packages, Ishmael and M3R, to supply acoustic data and metadata across the interfaces. Our "back end" implementations will encode DCL algorithms that can be plugged into any of the front ends to analyze acoustic data supplied across the interfaces. The aim is to make it simple for users to take advantage of these algorithms, and for developers to implement new methods in a simple, straightforward way and thus make them available to end users. We will conduct performance assessments of the improved algorithms and software interfaces using annotated data sets in the laboratory, and perform a demonstration using real time data at a US Navy instrumented range.

## APPROACH

**Odontocete click detection and classification**. A multiclass support vector machine (SVM) classifier was previously developed (Jarvis et al. 2008). This classifier both detects and classifies echolocation clicks from five species of odontocetes, including Blainville's and Cuvier's beaked whales, Risso's dolphins, short-finned pilot whales, and sperm whales. Here Moretti's group, especially S. Jarvis, will improve the SVM classifier by resolving confusion between species whose clicks overlap in frequency. The proposed work will investigate alternate feature sets to better separate species in the SVM's decision space.

Roch et. al's current real-time system for odontocete click classification is based upon Gaussian mixture models using cepstral feature vectors. Cepstral feature vectors provide a compact representation of the spectrum (Rabiner and Juang 1993) that let the system represent echolocation spectra using a reduced number of coefficients, providing a lower-dimensional feature space than using a standard representation of the spectrum. This system will be extended to cover more species and more recording/noise environments. In a separate project, Roch is working with personnel at Univ. Calif. San Diego on developing new features based on subspace models and improved noise compensation. The subspace models use hierarchical principal components analysis and random-projection trees (Freund et al. 2007) to learn new feature sets that will be used in place of cepstral feature vectors. The noise modeling will examine how to more effectively estimate background noise and compensate for it, taking into account interactions between noise and source (Ross 1976).

**Tonal signal detection and classification**. "Tonal signal" is a generic term for frequency-modulated calls such as baleen moans or odontocete whistles. Methods for detecting and classifying such sounds will be developed and applied to both odontocete whistles and to vocalizations from blue (*Balaenoptera musculus*), minke (*B. acutorostrata*), and humpback (*Megaptera novaeangliae*) whales. The methods to be developed here determine the species associated with odontocete whistles that are extracted automatically via the *Silbido* tonal contour following system (Roch et al. 2010). Research led by Roch focuses on the areas of signal processing and *Silbido*'s search algorithm to further refine this algorithm. Echolocation clicks result in broad-band energy producing interfering peaks in the time-frequency domain. These will be mitigated by locating echolocation clicks through an existing detection algorithm (Soldevilla et al. 2008, Roch et al. 2011) based on Teager energy (Kaiser 1990, Kandia and Stylianou 2006), and then removing it by interpolation.

In observing expert analysts classify whistles to species, we have noted that experts tend to comment on the general shape of a whistle. Extracted contours will be classified to species using hidden Markov models which are capable of modeling temporal transitions, thus exploiting the shape. HMMs have been used previously to classify signature whistles to groups, but a general approach requires more general models that can capture inter-specific variation. We propose segmenting whistles into components based upon easily identifiable landmarks (e.g. inflection points), and creating multiple models for components based upon cluster analysis.

Another approach will be to develop improved feature extraction methods that are based on processing units in the mammalian visual and auditory systems. It has been known for nearly 50 years that neurons in the visual cortex are sensitive to lines and surface edges in the visual field (Hubel and Wiesel 1962, Landy and Movshon 1991), and for at least 25 years that the auditory system has similar units for detecting frequency changes in tonal signals at specific frequencies (Mendelson and Cynader 1985). Mellinger and Martin will lead the effort to test some feature extraction and classification methods that use similar types of processing – specifically, developing processing units that respond to frequency change of a tonal signal within a narrow frequency range at specified FM rates, then modeling the time evolution of these units using a hidden Markov model (HMM) as described above.

**Advanced localization algorithms**. The first requirement for passive acoustic localization of marine mammals is the need to associate the detection of an individual signal as it is received across the array of widely spaced hydrophones. Moretti will lead the effort to develop a "nearest neighbor" approach to detection association. This approach will still use TDOA/hyperbolic methods, but will not discard TDOA from pairs of detections when the normally requisite 3 detections are not achieved. Rather,

detections from a given hydrophone will be associated with detections from all of its nearest neighbors and pair-wise TDOAs will be calculated.

Mellinger will also lead an effort to investigate an advanced localization method that employs the full cross-correlation function. The standard TDOA method extracts the position of the peak of the cross-correlation function between two hydrophones, and effectively ignores the rest of the cross-correlation. If the wrong peak is picked – which can happen easily due to multipath effects or, less commonly, interfering sounds – there is no information present to indicate that any other choice may have been nearly as good. Here we propose to use a system that uses the entire cross-correlation function for each hydrophone pair in finding the optimum location.

**Software and interfaces**. An Application Programming Interface (API) is a specification of a set of procedure calls (for objects, methods), data types (scalars, structures, classes, etc.), and protocols for use of the procedures and data types. A properly constructed and documented API makes it relatively simple for a developer to add new algorithms to an existing system. Systems with well-designed APIs permit users to add new functionality in a straightforward manner. Ishmael's (Mellinger 2001) interfaces for detection and localization comprise a relatively complex set of object class methods (procedure calls) and data types; although it is standardized, it is hardly straightforward or well-documented. The M3R system (Morrissey et al. 2006) has a format for standardized data serving and detection message passing using multicast over dedicated private networks. M3R also has a message-passing facility to share detection and classification results (i.e., notification of detection/classification events). Martin, Moretti, and Mellinger will lead the effort to develop and test APIs to make it relatively simple for developers to code new algorithms and test them in the Ishmael and M3R systems.

## WORK COMPLETED

Since the start date of July 1, 2011, we have primarily been (1) planning the project, (2) obtaining data sets and making them available to project members, and (3) wrangling the funding to direct it to project members.

(1) We have established regular (typically every 2-3 weeks) project teleconference meetings to discuss both technical details and project logistics. We also had a face-to-face kickoff meeting with most project members on Aug. 23, 2011 during the Mt. Hood DCLDE workshop. Our next face-to-face meeting is planned to occur during the Acoustical Society meeting in San Diego at the beginning of November.

(2) Klay established a web-accessible site for data sharing and placed five initial annotated (labeled) data sets in it. This site is accessed at ftp.pmel.noaa.gov with username ADCL; contact the authors for required further login information.

(3) Funding has reached both Navy partners (Martin (SPAWAR) and Moretti (NUWC)), and has nearly reached NOAA PMEL; it has been held up because a Memorandum of Understanding was required to be established between the Navy and PMEL, and it turns out that that is a lengthy process. This is very nearly done, and then the funds will be available to Klay and can be transferred to Mellinger (OSU) and Roch (SDSU).

## RESULTS

No significant results have been generated yet because the project just started the month before last.

## IMPACT/APPLICATIONS

For the Navy, passive acoustic monitoring (PAM) provides a means of long-term monitoring of many cetacean populations, especially over areas of high interest. Such areas are repeatedly subjected to Navy exercises involving intense sounds, especially multi-ship mid-frequency active (MFA) sonar. Currently, required environmental monitoring is dependent primarily on visual line transect surveys that are costly and, in the case of aerial surveys, significantly dangerous. In both the areas critical to the Navy and in other areas critical to marine mammals, PAM is dependent on automated DCL methods. The advanced DCL algorithms being developed here will make PAM more effective and efficient; the algorithm implementations across standardized interfaces that handle both real-time and pre-recorded data streams from diverse platforms will make them available to Navy fleet operators as well as the wider marine mammal research community.

## RELATED PROJECTS

“Passive Acoustic Monitoring for the Detection and Identification of Marine Mammals" (N00014-08-1-1199) award from ONR to PI Roch in 2008-10. This effort helped produce the *Silbido* detector that will be the basis for the research here in tonal sound detection and classification.

“Passive Autonomous Acoustic Monitoring of Marine Mammals with Seagliders” (N00014-10-1-0387) award from ONR to Mellinger and Klinck. The methods developed here are likely to be implemented in the Seaglider acoustic system for real-time detection and classification of marine mammal sounds.

“Detection, classification, and density estimation of marine mammals” (N00244-11-1-0026) award from N45 to Mellinger and Klinck. This effort includes some preparation of data sets that may be used for training and testing detection methods.

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